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Review

The neural basis of visual processing and behavior in cephalopods

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SUMMARY

Coleoid cephalopods (octopuses, squids and cuttlefishes) are the only branch of the animal kingdom outside of vertebrates to have evolved both a large brain and camera-type eyes. They are highly dependent on vision, with the majority of their brain devoted to visual processing. Their excellent vision supports a range of advanced visually guided behaviors, from navigation and prey capture, to the ability to camouflage based on their surroundings. However, their brain organization is radically different from that of vertebrates, as well as other invertebrates, providing a unique opportunity to explore how a novel neural architecture for vision is organized and functions. Relatively few studies have examined the cephalopod visual system using current neuroscience approaches, to the extent that there has not even been a measurement of single-cell receptive fields in their central visual system. Therefore, there remains a tremendous amount that is unknown about the neural basis of vision in these extraordinary animals. Here, we review the existing knowledge of the organization and function of the cephalopod visual system to provide a framework for examining the neural circuits and computational mechanisms mediating their remarkable visual capabilities.

Introduction

Cephalopods, particularly octopuses, squids, and cuttlefishes, present a fascinating opportunity for investigating the neural basis of vision. In some ways, their visual system is similar to ours[1]. Despite being part of a branch of the animal kingdom related most closely to slugs and snails, cephalopods have evolved a large brain comparable in size to that of some vertebrates[2]. Evolution also paired this large brain with a pair of camera-type eyes that are remarkably similar to ours, with a pupil and lens that projects a high-resolution image onto a retina densely packed with photoreceptors[3].

However, many aspects of the cephalopod visual system are profoundly different from those of other animals. The only neurons in the retina are photoreceptors, which transmit signals directly to the brain via the optic nerves, and surprisingly, the brain itself sends a large number of projections back to the photoreceptors in the eye[3]. The cephalopod brain bears no direct resemblance to the vertebrate brain, consisting of a series of fused ganglia[4], and it is dominated by vision, as the optic lobes occupy roughly two-thirds of the central brain[5]. The exterior layers of the optic lobe have a striking morphological similarity to the retina of vertebrates, but are located within the brain rather than within the eye. Behaviorally, cephalopods share many advanced visual capabilities with vertebrates, such as the ability to use vision to navigate, detect prey, and learn to recognize objects[6]. But they also possess unique capabilities that are beyond those of vertebrates, including the ability to sense aspects of light that are outside our perception, and the ability to rapidly change their skin patterning to camouflage instantly to their surroundings.

For a visual neuroscientist, there is tremendous appeal in the prospect of studying a powerful visual system that is radically unlike any other, and yet relatively unexplored at the neural level. Decades of research have revealed some basic aspects of the cephalopod visual system, including its basic anatomy and the behaviors it drives. Nevertheless, there remains a tremendous amount that is unknown about how this independently evolved visual system actually functions at the neural level, making this a compelling open field for study. Did the cephalopod brain converge on similar visual computations to other species? Or did cephalopods evolve completely different, and perhaps unexpected, solutions to analyzing visual scenes with neural circuitry?

Here we review what is known about the neural basis of cephalopod vision, including both classic work and recent studies that have begun applying modern techniques to investigate its organization and function. We focus on three main aspects of vision — visual behaviors, neural circuit organization, and neural function. We also highlight promising areas of study that we hope will accelerate research on cephalopod vision in the future.

Throughout this review, we focus on the coleoid cephalopods (octopuses, squids, and cuttlefishes), which all have camera-like eyes and elaborated visual systems that mediate complex visual behaviors. However, even within the coleoids, there is a large diversity of body plans, lifestyles, and ecological niches, with a corresponding diversity of visual system organization and function. Hence, it is an oversimplification to describe 'the' cephalopod visual system, particularly since many studies of cephalopod vision have focused on a limited handful of model species. Nonetheless, our goal here is to present a high-level synthesis, drawing on findings from different species and delineating both general principles and specific results.

The Neural Basis Of Behavior

Harold Saxton Burr

The Neural Basis Of Behavior:

The Neural Basis of Behavior A.L. Beckman,2012-12-06 The Symposium on the Neural Basis of Behavior from which this volume was produced was held at the Alfred I duPont Institute on June 7 and 8 1979 It brought outstanding investigators in four fundamental areas of behavioral neurobiology into juxtaposition there to provide an integrated multidisciplinary perspective on behaviorally significant brain mechanisms Particular emphasis was placed on topics of interest to neurobiologists as well as to clinicians in neurological and psychiatric disciplines The session on central activity states was selected as an appropriate point of departure because the continuum of brain activity states extending from the natural depression of hibernation through the heightened levels of arousal accom panying learning is such a clear and basic determinant of behavioral output The papers on learning and memory outlined diverse approaches to un derstanding the basis of these interrelat d CNS capabilities that constitute the neural basis of behavioral adaptation Finally the topics of affective states and mechanisms of pain provided a focus of clinically relevant discus sion covering multiple levels of functional and anatomical CNS organiza tion The success of the symposium bore testimony to the excellence of the presentations and to the symbiosis of their content both are preserved herein The support and encouragement of Dr G Dean MacEwen Medical Director of the Alfred I duPont Institute is gratefully acknowl edged Alexander L Beckman Wilmington July 1979 The Neural Basis of Behavior PART I Central Activity States Copyright 1982 Spectrum Publications Inc **The Neural Basis of Behavior** Alexander L. Beckman,1982-01-31 The Neural Basis of Human Prosocial Behavior Yefeng Chen,Hang Ye,Chao Liu,Qi Li,2019-12-19 **The Neural Basis of Behavior** Lloyd Stuart Woodburne,1967 **Perspectives of Motor Behavior and Its Neural Basis** Marie-Claude Hepp-Reymond,Gabriella Marini,1997-01-01 This publication provides the reader with a better understanding of some basic principles of motor behavior and gives an update on modern approaches of human motor control It contains abundant information on the current trends and illustrates the progress from laboratory findings to the investigation of more natural movements as well as of the cognitive aspects of motor behavior As an additional benefit for the reader the collected data is put in a historical perspective Basic and clinical neuroscientists rehabilitation specialists physiotherapists and in particular students in system neuroscience robotics and bioengineering will find this book a noteworthy contribution to the field **The Neural Basis of Human Behavior** Harold Saxton Burr,2003-01-01 **The Neural Basis of Mentalizing** Michael Gilead,Kevin N. Ochsner,2021-05-11 Humans have a unique ability to understand the beliefs emotions and intentions of others a capacity often referred to as mentalizing Much research in psychology and neuroscience has focused on delineating the mechanisms of mentalizing and examining the role of mentalizing processes in other domains of cognitive and affective functioning The purpose of the book is to provide a comprehensive overview of the current research on the mechanisms of mentalizing at the neural algorithmic and computational levels of analysis The book includes contributions from prominent researchers in the field of social cognitive and affective neuroscience as well as from

related disciplines e g cognitive social developmental and clinical psychology psychiatry philosophy primatology The contributors review their latest research in order to compile an authoritative source of knowledge on the psychological and brain bases of the unique human capacity to think about the mental states of others The intended audience is researchers and students in the fields of social cognitive and affective neuroscience and related disciplines such as neuroeconomics cognitive neuroscience developmental neuroscience social cognition social psychology developmental psychology cognitive psychology and affective science Secondary audiences include researchers in decision science economics judgment and decision making philosophy of mind and psychiatry **Mapping the Neural Basis of Motivated Behavior** William Edward Allen,2019 Understanding what in the brain establishes specific motivational states and how these states cause animals to pursue particular goal directed behaviors are central goals of behavioral neuroscience Fully determining the mechanisms underlying these processes will require a comprehensive description of how the brain operates at different levels spanning multiple spatial and temporal scales from the expression of individual genes within single cells to the coordinated activity of brain wide networks of neurons As a step towards this ultimate goal this dissertation proposes several new approaches to map and understand the structural functional and molecular properties of neural circuits These approaches are applied to study the circuits underlying motivated behavior with an emphasis of thirst motivation This work is divided into several parts 1 I de scribe the application of a method for labeling neural circuits defined by activity TRAP in combination with whole brain clearing and imaging technology to map the location of neurons activated by a particular experience throughout the brain and study their structural and molecular properties 2 Extending the idea of brain wide imaging to study dynamics I introduce two new approaches to perform large scale in vivo imaging of neural activity across the surface of the mouse brain to study cell type specific cortical dynamics involved in production of a simple thirst motivated choice behavior 3 I dis cuss an improved approach to TRAP and apply this technique to measure and manipulate a crucial node in the neural circuit underlying the sensation of thirst to reveal how activity in this circuit induced by water deprivation produces an aversive drive that is diminished through water consumption 4 I develop a new approach to spatially map the expression of up to 1 000 genes simultaneously in three dimensions within single cells in a tissue section and show that this approach is compatible with activity measurement using activity regulated genes as a post hoc reporter of neural activity 5 Finally I develop an approach using large scale electrophysiology to study spatially localized activity dynamics from cells distributed throughout the entire mouse brain I apply this technique to study brain wide neural dynamics during thirst motivated choice behavior revealing how thirst motivational state is represented throughout the brain and how this state gates the flow of information from sensory to motor regions *Neurobiology of Social Behavior* Michael Numan,2014-07-17 Social neuroscience is a rapidly growing interdisciplinary field which is devoted to understanding how social behavior is regulated by the brain and how such behaviors in turn influence brain and biology Existing volumes either fail to take a

neurobiological approach or focus on one particular type of behavior so the field is ripe for a comprehensive reference which draws cross behavioral conclusions This authored work will serve as the market s most comprehensive reference on the neurobiology of social behavior The volume will offer an introduction to neural systems and genetics epigenetics followed by detailed study of a wide range of behaviors aggression sex and sexual differentiation mating parenting social attachments monogamy empathy cooperation and altruism Research findings on the neural basis of social behavior will be integrated across different levels of analysis from molecular neurobiology to neural systems behavioral neuroscience to fMRI imaging data on human social behavior Chapters will cover research on both normal and abnormal behaviors as well as developmental aspects 2016 PROSE Category winner Honorable Mention for Biomedicine and Neuroscience Presents neurobiological analysis of the full spectrum of social behaviors while other volumes focus on one particular behavior Integrates and discusses research from different levels of analysis including molecular genetic neural circuits and systems and fMRI imaging research Covers both normal and abnormal behaviors Covers aggression sex and sexual differentiation mating parenting social attachments empathy cooperation and altruism **The Evolving Brain** C. H. Vanderwolf,2007-04-30 This book presents a series of essays on neuroscientific aspects of human nature and instinctive behavior individually acquired learned behavior human bipedal locomotion voluntary movement and the general problem of how the brain controls behavior The author argues that concepts of the mind based on ancient Greek philosophy are past usefulness and that modern animal behavior studies provide a better guide to the functional organization of the brain

Review Articles on the Neural Basis of Learning and Behavior in Nonhuman Primates Jean Balch Williams,1984

Behavioral Neuroscience George Spilich,2023-05-16 Behavioral Neuroscience by George Spilich presents the neurophysiological aspects of behavior to the 21st century digital native learner in the context of human experience rather than in that of laboratory experiments with non human animals Whether a student has enrolled in the course to prepare them for a career in medicine or science or they are fulfilling a general education science requirement Behavioral Neuroscience is written to meet them where they are The text has an accessible writing style real life examples and data sets active learning exercises and multimodal media and quizzes all designed to make the subject more engaging and relevant This ground breaking first edition is ideal for the Introductory Behavioral Neuroscience or the Biological Psychology course

Characterizing the Neural Basis of Individual Differences in Behaviors Using Large-scale, Population-based Neuroimaging Studies Weiqi Zhao,2022 Much of our understanding of the neural basis of behavioral differences are attributable to studies conducted with magnetic resonance imaging MRI Despite its critical role in cognitive neuroscience MRI findings lack generalizability for translational uses due to the small and homogeneous samples of traditional MRI studies To improve on the generalizability issue large scale population based neuroimaging studies are conducted where MRI data are collected from thousands of participants that are systematically sampled to represent the general population Now we

have a unique opportunity to harness the statistical power afforded by population based neuroimaging studies to characterize and quantify the behavioral relevance of MRI measures at the population level The goal of this work is to take advance of a population based neurodevelopmental study the Adolescent Brain Cognitive Development ABCD Study to shed light on the optimal fMRI design and analysis pipelines for the detection of behaviorally relevant brain signals In Chapter 2 I challenged the traditional statistical mapping approach of MRI analysis which assumed that the behavioral differences are explained by sparse localized brain regions I demonstrated that at a large population level the effects of the association between brain activations and behavioral differences are not sparse but distributed across the cortex Chapter 2 Aggregating the small effect sizes across the whole cortex can greatly increase the magnitude of the behavioral associations detected by fMRI tasks This finding is consistent with the observation that behavioral differences are associated with individual differences in distributed functional brain networks whose activities are measured by functional connectivity FC the pairwise correlation of activation across brain regions In Chapter 3 I carried out a systematic investigation of the optimal fMRI paradigms for the detection of behaviorally relevant FC patterns by quantifying the behavioral prediction performance of FC patterns derived from resting state fMRI and task fMRI Results showed that behaviorally relevant functional brain signals are better captured by task fMRI paradigms where participants are engaged in cognitive tasks that assess similar mental constructs as the behavior of interest These results suggest that carefully designed fMRI tasks and advanced statistical methods that capture the distributed effect sizes of the brain are more useful for the study of brain behavior relationships at the population level **The Organization of Behavior** D.O. Hebb,2005-04-11 Since its publication in 1949 D O Hebb s The Organization of Behavior has been one of the most influential books in the fields of psychology and neuroscience However the original edition has been unavailable since 1966 ensuring that Hebb s comment that a classic normally means cited but not read is true in his case This new edition rectifies a long standing problem for behavioral neuroscientists the inability to obtain one of the most cited publications in the field The Organization of Behavior played a significant part in stimulating the investigation of the neural foundations of behavior and continues to be inspiring because it provides a general framework for relating behavior to synaptic organization through the dynamics of neural networks D O Hebb was also the first to examine the mechanisms by which environment and experience can influence brain structure and function and his ideas formed the basis for work on enriched environments as stimulants for behavioral development References to Hebb the Hebbian cell assembly the Hebb synapse and the Hebb rule increase each year These forceful ideas of 1949 are now applied in engineering robotics and computer science as well as neurophysiology neuroscience and psychology a tribute to Hebb s foresight in developing a foundational neuropsychological theory of the organization of behavior *The Neural Basis of Hyperactive Wheel Running Mice* Justin S. Rhodes,2002 *The Neural Basis of Human Belief Systems* Frank Krueger,Jordan Grafman,2012-08-21 Is the everyday understanding of belief susceptible to scientific investigation Belief is one of the most commonly used yet

unexplained terms in neuroscience Beliefs can be seen as forms of mental representations and one of the building blocks of our conscious thoughts This book provides an interdisciplinary overview of what we currently know about the neural basis of human belief systems and how different belief systems are implemented in the human brain The chapters in this volume explain how the neural correlates of beliefs mediate a range of explicit and implicit behaviours ranging from moral decision making to the practice of religion Drawing inferences from philosophy psychology psychiatry religion and cognitive neuroscience the book has important implications for understanding how different belief systems are implemented in the human brain and outlines the directions which research on the cognitive neuroscience of beliefs should take in the future The Neural Basis of Human Belief Systems will be of great interest to researchers in the fields of psychology philosophy psychiatry and cognitive neuroscience **Behavioral Neuroscience** Carl W. Cotman,James L McGaugh,2014-04-24 Behavioral Neuroscience An Introduction provides a basic understanding of what is known about the means by which neurons communicate and about the nervous system which interprets integrates and transmits signals into meaningful and appropriate behaviors The book starts with an overview of the nervous system The text then describes the general operation and organization of the nervous system and some of the major types of neurons in the context of their systems The basic characteristics of neurons and how they communicate the processes and the basic integrative properties of defined groups of neurons and complex learning and memory are also considered The book further tackles the auditory somesthetic olfactory gustatory visual and motor systems the functions of the autonomic nervous system and the neuroendocrine system and the neural basis of two types of motivated behavior drinking and feeding The text also encompasses sleep and activity rhythms the development of the neural circuitry and its plasticity throughout life and the development of behavior Behavioral disorders and the aspects of the human nervous system which make man unique among all living creatures are also looked into Behavioral psychologists behavioral neuroscientists and psychobiologists will find the book invaluable **The Neuroscience of Organizational Behavior** Constant D. Beugré,2018-04-27 The Neuroscience of Organizational Behavior establishes the scientific foundations of organizational neuroscience a nascent discipline that explores the neural correlates of human behavior in organizations The book draws from several disciplines including the organizational sciences neuroeconomics cognitive psychology social cognitive neuroscience and neuroscience The topics discussed include the neural foundations of organizational phenomena such as decision making leadership fairness trust and cooperation emotions ethics and morality unconscious bias and diversity in the workplace **The Development and Neural Bases of Higher Cognitive Functions** Adele Diamond,1990 **The neural basis of visually guided behavior** Jörg-Peter Ewert,1974

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